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Habit in Pollution
A Challenge for Intergenerational Equity *

Ingmar Schumacher† Benteng Zou‡

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†CORE, Université catholique de Louvain, 34 Voie du Roman Pays, 1348 Louvain-la-Neuve, Belgium. E-mail:schumacher@core.ucl.ac.be.

‡Institute of Mathematical Economics, Bielefeld University, Postfach 100131, 33501, Bielefeld, Germany. E-mail: bzou@wiwi.uni-bielefeld.de.

Abstract

In this article we extend the recent literature on overlapping generations and pollution by allowing each generation's utility to depend on past levels of pollution. To conform with the literature on habit in consumption we call this extension habit in pollution. Habit in pollution can visualize itself as either a concern for the flow of pollution only, or for the stock, or anything in between.

We show that habit in pollution has not only significant consequences for the level of pollution and capital, but also for the evolution of utility over time. We observe that habit in pollution can lead to violations of two standard criteria of sustainability, which suggests that habit in pollution can be another source of intergenerational inequity.

JEL Classification: Q20, I31.

1 Introduction

Economists have recently started to pay more and more attention to the intergenerational aspects of environmental degradation (e.g. John and Pecchenino, 1994; Howarth, 1997; Pezzey and Toman, 2002; Seegmuller and Verchère, 2004). If generations are able to transfer the costs of their actions to the future, then this could deprive the latter of at least some of the welfare, which theories of intergenerational equity would have prorated to them. Our focus in this article is to characterize a different source of intergenerational *in*equity, one where one need not look to the deep future to observe violations of equity criteria. This source of potential intergenerational inequity arises under a seemingly favorable condition when generations are able to adapt to existing levels of pollution. In line with the recent literature on bequeathed tastes we dub this habit in pollution.

We analyze the implications of habit in pollution in an overlapping generations framework à la John and Pecchenino (1994) and specifically Seegmuller and Verchère (2004). Past levels of pollution are assumed to influence the way generations perceive the environment. We model this in a general way by allowing the utility to be a function of either the changes in pollution in one limit case, or, in the other limit case, utility will be a function of the stock of pollution.

The new element, which we introduce, has similar properties as the habit factor in consumption, which has seen some recent research by e.g. de la Croix (1996) and Wendner (2002). However, habit in pollution can have a different and larger variety of interpretations.

Firstly, habit in pollution could reflect the psychological adaptation to existing levels of pollution. A simple example can illustrate this interpretation. A generation, born at a certain point in time, will be born with an existing stock of pollution. However, this generation will not know the world any different. Hence, it will view the world it lives in as one without pollution. So, the only effect of pollution that this generation might feel is the change in the pollution stock during the time of its existence. We generalize this idea by allowing the generations to be concerned with either the stock of pollution, or the change in pollution during their lifetime, or anything in between. Secondly, habit in pollution can reflect the way pollution is noticed in the environment. For example, some pollutants are invisible or only occur in the ground, wherefore the general public might not fully notice the level but only know the amount they emit each period. Lastly, habit in pollution could refer to physical adaptation (where the factor would be very low and pollution would be interpreted as bodily harm).

These interpretations may not be applicable at the same time and are depending on the type of pollutant. Of these three interpretation, we shall utilize the first one throughout the article. Up to now there is no empirical research on whether habit in pollution exists or not. However, Scitovsky (1992) provides evidence from psychology suggesting that people respond to stimuli, i.e. changes, rather than levels. Similar arguments have been forwarded by Madruga and da Silveira (2003), who suggest that "we are stressed out by unprecedented levels of environmental (...) destabilization and somehow we are getting used to it." This argument captures what we describe as the psychological adaptation effect and seems to be the strongest argument in favor of habit in pollution.

One of our results is that habit in pollution bears significant effects upon the steady state levels of pollution and capital. Our main result, however, is that habit in pollution can have profound implications for intergenerational equity.

Overlapping generation models, even most continuous time growth models, augmented with an environmental constraint (e.g. John and Pecchenino, 1994) possess clear dynamics. Utility either increases or decreases over time given an optimal choice of consumption and abatement. Only very few models actually create non-monotonic behaviour in form of cycles and bifurcations (Bréchet and Lambrecht, 2004; Seegmuller and Verchère, 2004).

In the case of Bréchet and Lambrecht (2004), these bifurcations or cyclical behaviour are a result of the choice of a specific resource function. They provide no attempt in trying to explain the effect of these cyclical dynamics on intergenerational equity. Seegmuller and Verchère (2004) develop a similar model as we do, but with a utility function linear in consumption[1] and, most importantly, without a habit factor. Their main result is the

[1]However, they use a more general production function.

possibility of a flip bifurcation.

The interest in non-monotonic dynamics derives from an intergenerational equity point of view. If some generations possess the capacity to reduce future generation's utility in relation to their own, then most theories of intergenerational equity demand policy makers to act upon this behavior (e.g. egalitarianism). We are going to use an approach to intergenerational equity which is becoming standard in today's literature, namely to judge the model's implications upon its effects on the sustainability of welfare. One criterion of sustainability is Brundtland Sustainability, the other is Sustainable Development. We are able to show that habit in pollution will, under rather wide ranges of parameter choices, lead to violations of both criteria.

The paper is organized as follows. Section 2 introduces the basic features of the model and derives the intertemporal equilibrium. Section 3 describes the dynamics. Section 4 reviews the results within the theory of intergenerational equity. Section 5 concludes.

2 The Model

We consider a perfectly competitive overlapping generations economy. We allow for perfect foresight and discrete time with an infinite horizon, $t = 0, 1, 2....$ For simplicity we assume that population is constant and each generation consists of a single representative individual. At each date a generation lives for two periods, young and old. Furthermore, the young generations supply their labour inelastically and decide whether to save or invest (in abatement), and the old generations obtain utility from consuming their savings. In addition, we assume that the old generations feel the effects of pollution as a disutility, but perceive pollution differently for the various reasons as laid out in the introduction.

2.1 The Pollution Accumulation

Pollution is assumed to accumulate as described by the following equation

$$P_{t+1} = (1-b)P_t + \beta c_t - \gamma A_t, \tag{1}$$

where $b \in [0,1]$ is the rate of pollution absorption, $\beta(>0)$ is a parameter of consumption externality, representing the rate of pollution emissions from a unit of consumption, and $\gamma(>0)$ represents the effectiveness of the abatement effort, A_t, on pollution. Hence, the stock of tomorrow's pollution is partially depending on today's pollution stock and is being increased by consumption and reduced by abatement. What is important is the fact that the costs of today's consumption are transferred to tomorrow, which thus directly addresses the issue of intergenerational cost transferal. Notice also that we do not assume irreversibilities here.

Furthermore, we choose this pollution accumulation equation in preference for the environmental accumulation function à la John and Pecchenino (1994) because we feel uncomfortable with the assumption that the initial level of the environment must be above the natural level.[2]

2.2 The Generations

Generations derive utility over consumption and pollution only when old. Their utility function is of the form

$$U(c_{t+1}, P_{t+1}, P_t) = \ln c_{t+1} - \alpha \ln(P_{t+1} - hP_t), \tag{2}$$

where c_{t+1} refers to (per capita) consumption in period $t+1$, and P_{t+1} and P_t refer to the stock of pollution in periods $t+1$ and t respectively[3]. $0 < \alpha < 1$ measures each

[2] John and Pecchenino (1994) had to introduce this assumption in order to obtain a maximum for the first order condition.

[3] For any P_t and P_{t+1} there $\exists \hat{h}$ such that $P_{t+1} > \hat{h}P_t$, $\forall t$. Throughout the paper we assume that $h \leq \hat{h}$. We utilise this utility function in order to obtain simple and explicit solutions. Furthermore it is the only one which fits our assumptions. In addition, for $0 < P_{t+1} - hP_t < 1$, the effect of habit in pollution is able to increase utility.

generation's relative preference for pollution over consumption.

Thus, we extend the literature by allowing generations to be affected by past levels of pollution. For $h = 0$, generations perceive only the stock of pollution, for $h = 1$ they are only concerned with the flow, and for $0 < h < 1$ they are partly concerned with either.

Generations then maximize their utility with respect to savings and subject to their budget constraints which are given by

$$w_t - A_t = s_t, \tag{3}$$

$$(1 + r_{t+1})s_t = c_{t+1}, \tag{4}$$

and the pollution accumulation equation (1). Here, w, A, s and r refer to the wages obtained, the abatement effort, the savings carried forward to the next period and the interest obtained on the savings, respectively. The first order condition from the generation's maximization problem is

$$\frac{1}{s_t} = \frac{\alpha\gamma}{P_{t+1} - hP_t}. \tag{5}$$

This allows us to find the maximum of utility as the utility function is strictly concave with respect to savings, our variable of choice. The left-hand side of equation (5) gives the marginal benefit to utility of an additional unit of savings now, whereas the right-hand side gives the marginal costs to utility of a change in habit in pollution. The lower the relative preference of pollution with respect to consumption, as given by α, the more will each generation save in order to obtain a higher level of consumption when old. Also, the less each generation cares about the actual stock of pollution, i.e. a high h, the lower the level of savings. Finally, as generations are not altruistic, they don't take the effect of their consumption on next generation's utility into account. Therefore, they are only concerned with cleaning up some of the pollution their ancestors did. However, if they notice that their abatement efforts are not very effective, thus γ is low, then they will prefer to save more to obtain a higher level of consumption when old.

2.3 The Representative Firm

The representative firm produces with a constant returns to scale technology, $y = f(k)L$, where we normalise the labour supply to $L = 1$. We furthermore assume the standard conditions $f'(k) > 0$ and $f''(k) < 0$. The firm then maximizes profits in a competitive market that clears, such that

$$f'(k_{t+1}) - \delta = r_{t+1}, \tag{6}$$

$$f(k_t) - f'(k_t)k_t = w_t, \tag{7}$$

$$s_t = k_{t+1}. \tag{8}$$

We use the Cobb-Douglas output function to specify the production technology, with $f(k) = k^m$, where $m \in (0, 1)$ is the capital share. Furthermore, we assume full depreciation, $\delta = 1$, during the course of one period.

2.4 The Intertemporal Equilibrium

We first define the intertemporal equilibrium of this economy.

Definition 1 *Intertemporal equilibrium: The intertemporal equilibrium of the above depicted economy is a sequence* $\{k_t, P_t\}_{t=0}^{\infty}$ *with given initial conditions* $\{k_0, P_0\}$ *which satisfies the two equations that rule the dynamics,* (9) *and* (10).

By combining the first order condition with the market clearing condition, the output function, as well as the budget constraints and the pollution equation, we obtain

$$k_{t+1} = -\frac{1 - b - h}{\gamma(1 - \alpha)} P_t - \frac{m\beta + m\gamma - \gamma}{\gamma(1 - \alpha)} k_t^m \tag{9}$$

and

$$P_{t+1} = \frac{h + b\alpha - \alpha}{1 - \alpha} P_t - \frac{(m\beta + m\gamma - \gamma)\alpha}{(1 - \alpha)} k_t^m. \tag{10}$$

By taking $k_t = \overline{k}$ and $P_t = \overline{P}$, we derive the steady states of this economy. There exist two steady states, one is trivial with $\{\overline{k}, \overline{P}\} = (0, 0)$. The other steady state is given by

$$\overline{k} = \left(\frac{(1-h)(m\beta + m\gamma - \gamma)}{\gamma(b\alpha + h - 1)} \right)^{\frac{1}{1-m}}, \tag{11}$$

for $m\beta + m\gamma - \gamma \neq 0$ and $b\alpha + h - 1 \neq 0$, where $k > 0$ provided that $m\beta + m\gamma - \gamma$ and $b\alpha + h - 1$ have the same sign, as well as

$$\overline{P} = \frac{\alpha\gamma}{1-h} \left(\frac{(1-h)(m\beta + m\gamma - \gamma)}{\gamma(b\alpha + h - 1)} \right)^{\frac{1}{1-m}}. \tag{12}$$

Given the above reasoning, we shall from now on impose the following conditions.

Assumption 1 *We impose that $h < 1 - \alpha b$.*

This assumption shows that there exists a constraint on the level of h. If this constraint is violated then the generations adapt to existing levels of pollution so quickly that no steady state will exist. In effect, pollution will tend to infinity. One could furthermore take the case of long-lasting pollutants like climate change or nuclear waste, such that b is very small. This would allow to focus the analysis on an extensive range for the parameter of concern, h.

Assumption 2 *We assume $m\beta + m\gamma - \gamma < 0$.*

This assumption is equivalent to $\beta < \gamma \left(\frac{1}{m} - 1 \right)$. In general, the capital share is around $m = 1/3$, which leads to β being less than twice the value of γ. In other words, we allow that it takes less effort to pollute than to clean up. In addition, we notice that this assumption is consistent with a wide range of parameters for m, β and γ and is required for the existence of positive steady states.

The effect of habit in pollution on the steady state can be discovered by taking the derivative of (11) and (12) with respect to h. After rearranging we obtain

$$\frac{\partial \overline{k}}{\partial h} = -\frac{b\alpha\overline{k}}{(1-h)(1-m)(b\alpha + h - 1)} > 0. \tag{13}$$

Based on our Assumptions 1 and 2, the steady state capital stock increases with increases in the habit parameter, h. Obviously, if generations perceive the stock of pollution to be lower than it actually is, they will feel less concerned with it and thus produce more and abate less.

By similar calculation for (12) we obtain

$$\frac{\partial \overline{P}}{\partial h} = \frac{\overline{P}}{(1-h)(1-m)} \left[-m - \frac{1-h}{b\alpha + h - 1} \right] > 0. \tag{14}$$

Hence habit in pollution, h, will always increase the steady state stock of pollution[4]. Intuitively, if generations are less concerned with the actual stock of pollution, they will be willing to trade off a higher stock of pollution for a higher capital stock. This suggests that if generations adapt too fast to the stock of pollution such that mostly changes in pollution drive their utility, then they will allow pollution to accumulate without bound.

3 The Dynamics

By linearizing equations (9) and (10) around the non-trivial steady state we obtain the dynamics around the steady state.

We study a special case, where the regeneration of the nature itself is negligible, such that $b = 0$. This can be applied to various types of persistent organic pollutants, to nuclear waste or several long-lasting greenhouse gases. Then the pollution accumulation is given by

$$P_{t+1} = P_t + \beta c_t - \gamma A_t.$$

In this case, the characteristic function is

$$(1-\alpha)\lambda^2 - (h + m - \alpha)\lambda + mh,$$

with $h < 1$. The eigenvalues are given by

$$\lambda_{1,2} = \frac{(h + m - \alpha) \pm \sqrt{(h + m - \alpha)^2 - 4mh(1-\alpha)}}{2(1-\alpha)}. \tag{15}$$

[4] A sufficient condition for this is given by our assumption that $b \in (0, 1)$ and $\alpha < 1$.

As one can easily see, equation (15) allows for positive, negative as well as complex eigenvalues. The full conditions characterizing the dynamics can be found in the Appendix for reference only. However, as we would like to analyze the dynamics for their implications on intergenerational equity, we shall focus on the complex case. The following Proposition shows under which circumstances complex eigenvalues will appear.

Proposition 1 *If the parameter combination is such that* $h_1 < h < h_2$ *and* $\alpha + m - 2m\alpha > 0$*, then the system's orbit around the non-trivial steady state* $(\overline{k}, \overline{P})$ *is oscillatory, with*

$$h_1 = (\alpha + m - 2m\alpha) - 2\sqrt{\alpha m(1-\alpha)(1-m)},$$

$$h_2 = (\alpha + m - 2m\alpha) + 2\sqrt{\alpha m(1-\alpha)(1-m)}.$$

Proof 1 *See Appendix.*■

3.1 Interpretation of the complex dynamics

We notice that, at the intertemporal equilibrium, changes in capital and pollution are non-monotonic for certain parameter combinations due to the interplay of two elements: Firstly, the savings of the old (s_t) are utilized to produce the wages of the young and the consumption of the old (c_{t+1}). This transformation is subject to decreasing returns (as $f''(k) < 0$). The second element is a direct result of the habit in pollution. For $0 < h < 1$, generations are partly able to adapt to existing stocks of pollution ($P_{t+1} - hP_t$), wherefore they are spending less money on abatement and more on consumption. From a certain level of capital stock onwards, the additions to savings are so small that the increases in pollution outweigh the advantages from higher savings (s_t). Therefore, the generation spends more money on abatement (A_t), which reduces savings (s_t). This reduction has a two-fold impact. Firstly, the reduction in savings (s_t) reduces next periods capital stock (k_{t+1}) and thus consumption (c_{t+1}) and the pollution stock of the consecutive period (P_{t+2}); secondly, the increase in abatement (A_t) reduces the stock of pollution (P_{t+1}). Assuming the parameter combination that leads to complex dynamics, the next generation is now in a position where they view the effect of pollution on their utility ($P_{t+2} - hP_{t+1}$) as sufficiently small, which leads them to reduce abatement and increase savings. Depending on the parameter combinations, this adjustment process can be convergent, explosive or even lead to endogenous cycles of period two.

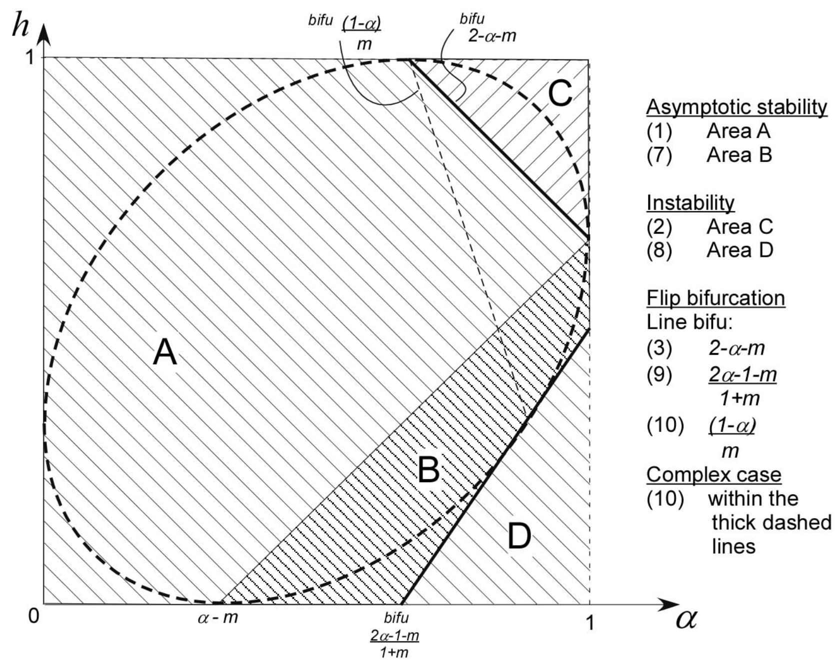

Figure 1: Stability conditions for $m = 1/3$

We use Figure 1 to show the combinations of h and α which lead to oscillations. In addition, Figure 1 visualizes under what parameter configurations one can expect stability and instability. The legend on the right-hand side explains which area is meant by which point of Proposition 1 (as well as the stability conditions given in the appendix).

This model, though seemingly simple, is rather rich in dynamics. It allows for positive, negative as well as complex eigenvalues, which permits various types of solution paths. Area A and B show the combinations of $h \in (0, 1)$ and $\alpha \in (0, 1)$ which lead to asymptotic stability, whereas areas C and D give the combinations leading to instability. The three lines labeled *bifu* are the parameter combinations that lead to bifurcations. The large oval area made by the thick, dashed line is the case of complex eigenvalues. For the case of complex eigenvalues, the steady states to the left of the line *bifu*, $\frac{1-\alpha}{m}$, are asymptotically stable, and the ones on the right are instable. One general observation is that the larger is m the more stable will the system be for small h and large α and less stable for large h and smaller α. The more we care about pollution relatively to consumption the more unlikely will be a stable steady state.

The case of bifucations has been well explained by Seegmueller and Verchère (2004). The consequences of instability are intuitive. In the following section we are therefore going to focus on the case of stability with complex eigenvalues and we shall utilize this case to highlight the consequences for intergenerational equity.

4 Welfare Analysis and Intergenerational Equity

As suggested in the previous section, habit in pollution can cause oscillatory dynamics for a large range of parameter values. Our focus in this section will then be to emphasize the implications of oscillatory dynamics on two widely used criteria of intergenerational equity. One criterion is Brundtland Sustainability, the other is Sustainable Development[5].

The first notion of sustainability, **Brundtland Sustainability**, was shaped in 1987 in the United Nations report *Our Common Future*, more commonly referred to as the Brundtland Report. The most widely quoted sentence of this report is that sustainability should be thought of as "meeting the needs of the present without compromising the ability of the future generations to meet their own needs". However, this sentence, on its own, is not a complete account of what the Brundtland Report has in mind by sustainability. The report furthermore suggests that sustainability "(...) requires meeting the basic needs of all and extending to all the opportunity to fulfill their aspirations for a better life." (Brundtland Report, p. 24) The second part of this interpretation of sustainability seems to have been neglected in today's literature. It is more closely connected to the new egalitarian thinking on capability and responsibility (see e.g. Roemer, 1996). It is nevertheless

[5] We are aware that the Brundtland report originally called its criterion Sustainable Development. However, here we follow recent expositions by Gosseries (2005) and Pezzey (1997).

not clear though, how we are to interpret the request to "extend to all the opportunity to fulfill their aspirations" in terms of an economic approach to intergenerational equity.

One interpretation could be that meeting the basic needs suffices and does not require further redistributions (see Pezzey, 1997). This is clearly a sufficientarian notion of justice. This theory of justice suggests that a distribution is just if all basic needs are covered. This then can be rewritten in utility terms, where it comes to denote that a minimum of utility, $u_t \geq \underline{u}$, is to be obtained for all subsequent, indefinite number of generations. We shall have this interpretation in mind when we refer to Brundtland Sustainability in the subsequent paragraphs.

Definition 2 *A path of utility* $\{u(t)\}_{t=0}^{\infty}$ *conforms with the Brundtland Sustainability criterion if* $u_t \geq \underline{u}$, $\forall t$, *where* $\underline{u} > 0$ *is a minimum level of utility.*

Another interpretation could be as follows: if we were to stay within the boundaries of this model, then each generation will have the same aspirations - maximizing their utility. Given rationality and perfect foresight[6] this implies that every generation should obtain at least the same level of utility as their ancestors did[7]. This is a much stronger demand than Brundtland Sustainability and - at least in our model - is closely connected to our second notion of sustainability. However, as this second interpretation of Brundtland Sustainability adds nothing more to our analysis, we shall leave it aside.

The second notion, **Sustainable Development**, is by now the predominant notion used in economic analysis (Solow, 1974; Daly and Cobb, 1994; Pezzey, 1997) as well as egalitarian thinking, but nonetheless not free of controversy. In economic terms it has been interpreted to mean that a certain level (or development) of utility is to be achieved. This has been taken to imply that $\frac{\partial u_t}{\partial t} \geq 0$, for all following time periods. Hence a world in which this criteria is utilized is one in which utility is either kept constant or increases over time, but is not reduced.

[6]Plus abstracting from various issues like population changes, changes in bundles of goods transferred between generations, etc.

[7]The part "at least the same level of utility" comes from the fact that capital is productive, $r(t) > 0$.

Definition 3 *A path of utility $\{u(t)\}_{t=0}^{\infty}$ conforms with the Sustainable Development criterion if $\frac{\partial u_t}{\partial t} \geq 0$, $\forall t$.*

We are now going to study the evolution of utility in order to understand which of the two criteria of sustainability are satisfied within our model. The following proposition summarizes the motion of utility at the intertemporal equilibrium.

Proposition 2 *The level of utility at the intertemporal equilibrium can be expressed as a function of the optimal capital stock only. In particular, the utility level is either pro-cyclical (if $m > \alpha$) or counter-cyclical (if $m < \alpha$) depending on the relative importance of pollution in generating utility.*

Proof 2 For the proof we utilize the utility function of each generation. We have that utility is equal to $u(\cdot) = \ln(c_{t+1}) - \alpha \ln(P_{t+1} - hP_t)$ and we substitute $c_{t+1} = (1 + r_{t+1})s_t$, which equals mk_{t+1}^m, and we substitute the FOC. Thus we get $\ln(mk_{t+1}^m) - \alpha \ln(\alpha\gamma k_{t+1}) = (m-\alpha)\ln(k_{t+1}) + \ln(\frac{m}{(\alpha\gamma)^\alpha})$. Hence, utility at the intertemporal equilibrium can be written as a function of the capital stock only. If $m < \alpha$ then utility is counter-cyclical, and for $m > \alpha$ utility will be pro-cyclical.■

Proposition 2 thus allows us to see that utility, at the intertemporal equilibrium, can be written as $u(k, P(k))$. Thus utility follows the motion of capital at the intertemporal equilibrium. Figure 2 describes the motion of utility at the intertemporal equilibrium for the case of complex eigenvalues and the steady state case[8].

It is possible to observe that generations will face different levels of utility depending on when they are born. If we assume that a policy maker assesses intergenerational equity by comparing the motion of utility at the intertemporal equilibrium with the requirements of the Sustainable Development criterion, then the oscillatory motion of utility at the intertemporal equilibrium prevents achieving this equity target without adequate policy

[8]We use the following parameter combinations for the simulations: $b = 0$, $h = 0.85$, $\gamma = 0.2$, $\alpha = 0.7$, $m = 0.3$, $\beta = 0.35$.

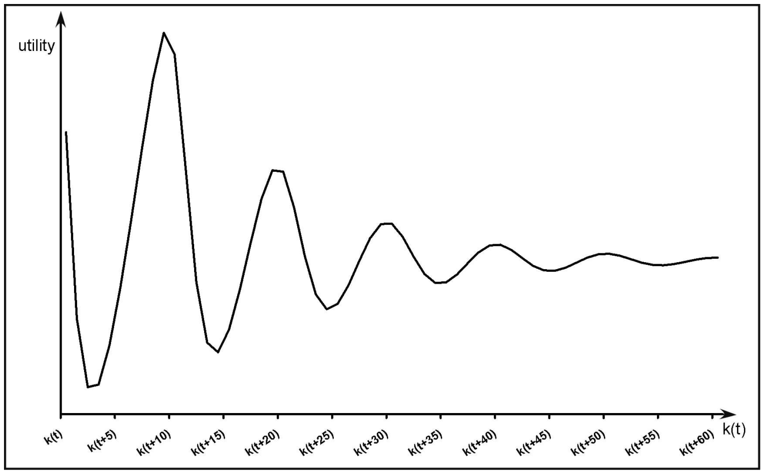

Figure 2: Motion of utility at the intertemporal equilibrium

interventions. These interventions could for example take the form of intergenerational transfers[9]. If we assume that a policy maker assesses intergenerational equity by comparing the motion of utility at the intertemporal equilibrium with the requirements of the Brundtland Sustainability criterion, then the result is far less clear. What we can say, however, is that besides the level of minimum utility, the initial conditions as well as the level of the habit in pollution parameter h and α play the predominant roles. The closer the parameter combination of h and α is to the parameter combination that leads to bifurcations, the larger the oscillations of utility at the intertemporal equilibrium.

5 Conclusion

In this article we extend the recent literature on overlapping generations and pollution by allowing generations to have habit in pollution. This can be interpreted as a psychological adaptation to existing levels of pollution and visualizes itself as a concern for the flow of pollution only, or for the stock, or anything in between.

[9]Arguments questioning the possibility of intergenerational transfers can be found in Lind (1995).

The effect of habit on the steady state level of pollution and capital is rather profound. The larger the habit factor, i.e. the more the generations only focus on the changes in pollution during their lifetime, the larger the steady state levels of pollution and capital. Most importantly, if generations are only concerned with the flow of pollution, then pollution will be accumulated without bound.

In addition to affecting the steady state levels of pollution and capital, habit in pollution also affects the way in which these steady state levels are reached. Whereas overlapping generation models without habit in pollution usually have monotonic dynamics (e.g. John and Pecchenino (1994)), our extension allows for a wide range of dynamics to occur. We find that for large choices of parameters the agent's behavior at the intertemporal equilibrium can lead to oscillations in utility of subsequent generations.

We analyze these oscillations for their effect on two standard criteria of intergenerational equity, Brundtland Sustainability and Sustainable Development.

In case these oscillations are to occur, then Sustainable Development will be impossible to achieve without adequate policy interventions. Furthermore, whether the Brundtland Sustainability criterion will be satisfied depends on the level of the minimum utility, the initial conditions as well as the level of the habit parameter and the relative importance of pollution in generating utility.

Our results can be slightly generalized. When a model generates endogenous cycles then both predominantly used criteria of intergenerational equity, Brundtland Sustainability as well as Sustainable Development, can be easily violated in case there are no policy interventions. This thus requires a certain trade-off between the value that generations place on efficiency, and the value that a policy maker places on intergenerational equity.

Habit in pollution is evidently a challenging extension for standard OLG models of the environment and deserves greater attention in consecutive research. Especially interesting would be to see whether empirical evidence is able to support this adaptive behavior of the agents, how a policy maker could affect this behavior and how forward-looking the policy maker must be in order to avoid the intergenerational inequities.

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Appendix

Proof of Proposition 1.

Notice that

$$\Delta(h) = \frac{(h+m-\alpha)^2 - 4mh(1-\alpha)}{2(1-\alpha)}$$

is the term under the square root of equation (15). To find the conditions under which $\Delta(h) < 0$ we equate $\Delta(h)$ with 0 and solve for h

$$0 = h^2 + 2h(2m\alpha - \alpha - m) + (\alpha - m)^2,$$

which has roots

$$h = (\alpha + m - 2m\alpha) \pm \sqrt{(\alpha + m - 2m\alpha)^2 - (\alpha - m)^2}$$

$$= (\alpha + m - 2m\alpha) \pm \sqrt{\alpha(1-\alpha)m(1-m)},$$

which are always real, for any $0 < \alpha < 1$ and $0 < m < 1$, except at $\alpha = \frac{m}{2m-1}$.

Denote

$$h_1 = (\alpha + m - 2m\alpha) - \sqrt{(\alpha + m - 2m\alpha)^2 - (\alpha - m)^2},$$

$$h_2 = (\alpha + m - 2m\alpha) + \sqrt{(\alpha + m - 2m\alpha)^2 - (\alpha - m)^2}.$$

So for the given α and m, $0 < h_1 < h_2 \leq 1$. Then we can see that if $\Delta(h) < 0$, the eigenvalues will be complex. ■

The complete conditions describing the dynamics

Let $h \in (0, h_1) \cup (h_2, 1)$, if furthermore, $0 < m < 1$, for any $\alpha \in (0,1)$, with $\alpha \neq \frac{m}{2m-1}$, and

(1) h checks $\max\{\alpha - m, 0\} < h < \min\{1, 2 - \alpha - m\}$, the nontrivial steady state is asymptotic stable.

(2) if $\min\{1, 2 - \alpha - m\} = 2 - \alpha - m$, when $2 - \alpha - m < h < 1$, the nontrivial steady state is instable

(3) and at $h = 2 - \alpha - m$, there is a Flip bifurcation.

(B) *Let $1 > m > \frac{1}{2}$, $1 > \alpha > \frac{m}{2m-1}(> m)$ and $h \in (0, h_1) \cup (h_2, 1)$,*

(4) and h checks $\alpha - m > h > \max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\}$, then the nontrivial steady state is asymptotic stable.

(5) If $\max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\} = 3\alpha - 2 - m$, and $h \leq 3\alpha - 2 - m$, the nontrivial steady state is instable. If $\max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\} = \frac{2\alpha}{1+m} - 1$, and $h < \frac{2\alpha}{1+m} - 1$ the nontrivial steady state is instable.

(6) At $h = \frac{2\alpha}{1+m} - 1$, there is a Flip bifurcation.

(C) *Let* $\alpha - m > h$ *and* $h \in (0, h_1) \cup (h_2, 1)$. *Suppose that* $0 < m < 1/2$ *and* $m < \alpha < 1$*; or* $1/2 < m$ *and* $m < \alpha < \frac{m}{2m-1}$.

(7) If h checks $\alpha - m > h > \max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\}$, then the nontrivial steady state is asymptotic stable.

(8) If $\max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\} = 3\alpha - 2 - m$, and $h \leq 3\alpha - 2 - m$, then the nontrivial steady state is instable. If $\max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\} = \frac{2\alpha}{1+m} - 1$, and $h < \frac{2\alpha}{1+m} - 1$ the nontrivial steady state is instable.

(9) If $\max\{\frac{2\alpha}{1+m} - 1, 3\alpha - 2 - m\} = \frac{2\alpha}{1+m} - 1$, then at $h = \frac{2\alpha}{1+m} - 1$, there is a Flip bifurcation.

(10) Complex eigenvalue case. See Proposition 1 in the main text. Also, denote $h^* = \frac{1-\alpha}{m}$, if α and m such that $h_1 < h^* < h_2$, then if $h_1 < h < h^*$, the steady state is asymptotically stable; if $h^* < h < h_2$, the steady state is instable; if $h = h^*$, there is a Flip Bifurcation.

Proof: Can be obtained from the authors upon request.■

The condition on **positive abatement** can be derived as follows: As $A_t = w_t - s_t$ and $s_t = k_{t+1}$, we can then substitute the solutions $w_t = f(k) - f'(k)k$ as well as the dynamical equation for k_{t+1}, as given by equation (9). Hence $A_t = (1-m)k_t^m + \frac{1-b-h}{\gamma(1-\alpha)}P_t + \frac{m\beta+m\gamma-\gamma}{\gamma(1-\alpha)}k_t^m$. The coefficient on pollution is always positive, so a sufficient condition for positive abatement is $0 \leq (1-m) + \frac{m\beta+m\gamma-\gamma}{\gamma(1-\alpha)}$, which implies that $\gamma \leq \frac{m\beta}{\alpha(1-m)}$.■